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NEW DEMANDS FOR APPLICATION OF NUMERICAL SIMULATION TO IMPROVE RESERVOIR STUDIES IN CHINA

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Abstract. After years of production, most oilfields with nonmarine deposits in China have been at their mature stage with high water cut and high recovery. The remaining oil is, on one hand, highly scattered in the reservoir, but on the other hand, relatively concentrated in some locations. The identification of the exact distribution of these locations with relatively abundant remaining oil is of great importance for improving oil recovery, but is very difficult. The oilfield development, which has been complicated by all the above factors, calls for more powerful numerical reservoir simulation techniques. The large-scale sophisticated numerical simulation technique with high efficiency, high precision, and high computing speed will be the key to the study on the remaining oil distribution for oilfields at their mature stage with high water cut. As for various types of complicated reservoirs, it is essential to develop different fluid flowing models and corresponding numerical simulation techniques.

Key Words. Oil reservoir, numerical simulation, high water cut, remaining oil distribution.

1. First section:Introduction

This is the first section. Statistics show that more than 90In addition, tertiary recovery techniques such as polymer flooding, alkaline/surfactant/ polymer combination flooding can be used in a lot of oilfields in China to enhance oil recovery. Moreover, a lot of fractured sandstone reservoirs with low and extra-low permeability have been found, the development of which is more complicated. Therefore, numerical simulation demands for improved functions in such cases.

2. Second section:Large-scale sophisticated numerical simulation technique

This is the second section.

2.1. Combining coarse-gridblock simulation with fine-gridblock simulation. This is the first subsection of the second section. In China, most reservoirs are very heterogeneous both horizontally and vertically. Reservoirs with nonmarine deposits usually have a large number of layers, even above one hundred, showing considerable differences in their properties. In addition, properties also change dramatically within the same layer. Therefore, it is of great importance to make clear the remaining oil distribution in reservoirs, especially those locations with relatively abundant remaining oil. In order to improve oil recovery of reservoirs of various types economically and effectively, it is crucial to drill highly efficient infilling wells

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at locations with relatively abundant remaining oil or to work out other practicable reservoir revitalization measures. In order to picture the horizontal heterogeneity and the large number of layers in the vertical direction, a tremendous number of grid nodes are needed, even reaching or exceeding one million. During the in-depth reservoir study, what we are interested in are the locations with relatively abundant remaining oil. Therefore, we should carry out simulation study with fine grid system only at those locations but not in the whole reservoir. Hence, the optimum practice is to start with a relatively coarse grid system to simulate the whole reservoir to find locations with relatively abundant remaining oil, and then turn to a more refined grid system for simulation at such locations. This strategy can reduce grid number and enhance simulation speed without compromising the precision of remaining oil distribution prediction.

2.2. Parallel computing technique. This is the second subsection of the second section. During the study on remaining oil distribution in mature oilfields, although the strategy of combining coarse-grid system with fine-grid one can reduce grid number and enhance simulation speed, the simulation, especially the history matching, will still consume a great deal of time due to a large number of wells, a lot of workovers, and a long production history. Thus, the simulation speed needs to be accelerated further in the case of large-scale sophisticated simulation. The core of numerical reservoir simulation is to solve a large-scale sparse system of linear equations, which is derived from a large-scale system of partial differential equations. Due to the large amount of time and costs that a large-scale sophisticated simulation needs, parallel computers are highly recommended. The emergence of high-performance parallel computers opens a new stage to numerical reservoir simulation techniques. The parallel computation technique for numerical reservoir simulation has become a hot research interest. In recent years many oil companies, service companies and research institutes at home and abroad employ parallel processing technique to lower production costs and enhance work efficiency. Several service companies have also launched numerical reservoir simulators of parallel computation version. China has carried out several key research projects concerning parallel computation since 1990. Research Institute of Petroleum Exploration and Development of PetroChina, China Academy of Sciences, Tsinghua University and others have all been involved in the study on the parallel computation for numerical reservoir simulation. The study on parallel computation for numerical reservoir simulation has laid a solid foundation for the study on large-scale sophisticated numerical reservoir simulation.

2.3. Streamline simulation technique. This is the third subsection of the second section. Although parallel computing technique has been well developed, it is still essential to develop streamline simulation technique with a higher speed when using simulators to predict the remaining oil distribution in mature oilfields. In a streamline simulation, the pressure equation is solved on an underlying grid system using the same method as in a conventional simulation. Next, a nature transport network is constructed based on the orthogonality between streamlines and pressure contours [2] and fluid is transported along streamlines to track oil/water/gas movement within the reservoir. The streamline method therefore has an inherent advantage because the fluid is transported just one dimensionally along streamlines and not between 3-D grid blocks. Because of this simplicity and greater stability, larger time steps with less sensitivity to grid block size and orientation can be used [3]. Displacement along any streamline follows a one-dimensional solution with no cross flow among streamlines. Therefore, well response is simply the summation of a series of 1D flow simulations. Compared with conventional simulations using Cartesian grid system, streamline models have two very significant applications /advantages. The applications/advantages are [4]: (1) Computing speed is faster, simulation capacity is larger, and the total history matching cycle for field-scale simulation can be reduced by 2-5 times. The equivalent gridblock number can be over one million. (2) Streamline technology allows easier visualization of both areas with remaining oil and injector-producer relationships than conventional simulation with Cartesian grid system.

2.4. Flexible grid technique. This is the fourth subsection of the second section. With the introduction of 3-D detailed geologic model, flexible grid technique should be developed in order to simulate complicated reservoirs of various types, sand body boundaries or faults, anisotropy of permeability in the vertical or lateral direction as well as the high-speed and high pressure gradient flow regimes in zones near the borehole. In recent years, flexible grid techniques including local grid refining, hybrid grids, angular point grids, PEBI, CVFE and complex unstructured grids [5] have been developed at home and abroad. However for some of these techniques, there is still some distance before they are put into commercial use.

2.5. Auxiliary software for history matching in large-scale sophisticated numerical simulation. This is the fifth subsection of the second section. When the large-scale sophisticated simulation, especially the history matching, is carried out using some existent simulators, a lot of problems can be met and need to be solved: (1) Dynamic data preparation is too time-consuming, and engineers are apt to make mistakes in such preparation. As for mature oilfields with a huge number of wells, a very long producing history, and undergoing a lot of workovers or measurements, it takes a great deal of time to prepare dynamic data, which must be input time step by time step for each well, and engineers are apt to make mistakes in the process of data preparing. (2) History matching process is complex and difficult. When analyzing wells performances and making history matching, some existent simulators cannot show which well is preferential for matching due to their larger errors and cannot display all the matching parameters, such as production, water cut, gas-oil ratio and bottom pressure, for the same well on screen simultaneously. Engineers have to search the matching parameters for a specific well from those for all the wells again and again. Such practice consumes a lot of time. (3) Information needed in history matching analyzing is insufficient. Many problems encountered in history matching come from multi-layering on the well profile. For example, when the production schedule of a well needs to change from a constant rate to a constant pressure for the production pressure differences in some layers may not be satisfied with this constant rate, the pressure in each layer should be analyzed, but the simulator cant offer relevant information on screen. Therefore, auxiliary software for large-scale sophisticated numerical simulation has to be developed in order to improve the efficiency and precision of history matching.

2.6. Injection and production rate allocation technique. This is the sixth subsection of the second section. The allocation of injection and production rate to a layer will affect the amount of remaining oil in that layer seriously. However, quite often the conventional methods to allocate injection and production rate to each layer by mobility cannot give satisfying results because the practical rates do not accord with the mobility of each layer due to interference among layers. If the production profile or water injection profile of wells have been measured precisely, the allocation of injection and production rate in each layer by these measurements will give good results. However, the injection or production profiles have been measured only in some wells, but were not measured in most wells. Also, the profile can only represent the time step that it is measured, but not all the time steps of a wells performance. So, it is necessary to develop new methods using all production and test data for allocating injection and production rate more accurately in order to enhance the precision of the identification of remaining oil distribution.

3. Coupling fluid flow with reservoir deformation

This is the third section. The conventional reservoir flow theory does not give the interaction between fluid flow and reservoir deformation resulted from pressure drop or temperature change in reservoir into consideration. However, in fact, the rock matrix is deformable. In a reservoir with low or extra-low permeability, the permeability is sensible to the pressure drop in the reservoir due to the change in pressure difference between overburden rock pressure and reservoir pressure. Hence, numerical simulation should simulate the multiphase flow and reservoir deformation simultaneously to estimate the effect of pressure sensitivity. And also when the temperature in a reservoir changes dramatically, the deformation of rock matrix will result in a change in permeability, and thus affect fluid flow. Therefore, it is necessary to couple fluid flow with reservoir deformation and to simulate them simultaneously in order to enhance the precision of the simulation.

4. Fractured reservoir simulation

This is the forth section. Low-permeable fractured sand stone reservoirs take up a large percentage of all the reservoirs in China. The flow mechanism in a fractured sand stone reservoir is different from the dual-porosity limestone system. The mathematical model put forward by Warren and Root [6] assumes that the distribution of fractures in the reservoir is uniform. But the study on fractured sandstone reservoirs indicates that the distribution of fractures is characterized by non-uniformity and discontinuity. The conventional theory from dual-porosity limestone system may be inappropriate, and new mathematical model needs to be developed.

5. Non-Newtonian and physiochemical fluid simulation

This is the fifth section. When simulating reservoirs at the stage of chemical tertiary recovery, the effect of non-Newtonian flow and the more complicated physiochemical phenomena for polymer flooding and alkaline/surfactant/polymer combination flooding must be considered. In past decades, significant progress has been made in these areas, and some simulators have been developed at home and abroad, especially for polymer flooding. However, there are still a lot of problems that need to be studied and the functions and the precision should be improved further.

6. Conclusion

This is the sixth section. Most oilfields with complicated nonmarine geology in China have been at their stage with high water cut and high recovery. The identification of the distribution of areas with relatively abundant remaining oil in order to improve oil recovery calls for the more powerful large-scale sophisticated reservoir simulation techniques. Therefore, simulation techniques such as combination of the coarse grid system and the fine one, parallel computation, streamline, flexible grid, and auxiliary software for history matching have to be developed. As for various types of complicated reservoirs, including low and extra-low permeability reservoirs, fractured sandstone reservoirs and reservoirs developed by chemical flooding EOR techniques, some new simulation techniques such as coupling fluid flow with rock deformation, new mathematical models about interaction between non-uniform fractures and matrix rocks, and non-Newtonian and physiochemical flow have to be studied and developed.

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